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# Research on Mechanism of over Current When Non-contact On-load Tap Changer Regulating Voltage

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**Abstract**

Automatic on-load voltage regulation of transformer is an effective method to stabilize load voltage. Mechanic contact tap changing is not adequate for distributing transformer because of its high cost and low capability. The paper presents the structure and automatic on-load voltage regulating principle of distributing transformer, which employs solid state relay as non contact automatic on-load voltage regulating tap changer . The generation mechanism and limiting measure of circular current that is occurred in the process of changing tap joint. By theoretical analysis and experimental verification, it is concluded that it has different occurring process of circular current when voltage is regulated to higher or lower value.

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*Keywords-distributing transformer; non- contact ; on-load tap changer ; solid state relay; generation mechanism*

## 1. Introduction

Automatic on-load voltage regulation of transformer is an effective measure to stabilize the power network voltage. At present, automatic mechanic contact tap changing switch is widely used in power system. It can not operate frequently. In addition, arc will occur when the switch changes, so it must be installed in independent oil tank.Cooke G H solved the problem that arc would occur when the switch changes by using on-load voltage regulating tap changing switch in which thyristor as its auxiliary switch[1]. But the device also has mechanic part and can’t operate frequently so the drawback still remains. Guorong Zhu series connects the primary side of auxiliary transformer with the main transformer. And he uses thyristor to change the secondary tap joint of auxiliary transformer to regulate voltage. It can operate quickly. And arc won’t occur. But this method needs complex auxiliary

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transformer and large capacity thyristor. It adds costs of the transformer and limits the switch's application field. Therefore it is not fit for distributing transformer for its cost and performance.

The power electronic component can be easily controlled and it can switch quickly. In addition, arc will not occur in the process of switching. If it is used as on-load tap changing switch of transformer, the switch will has low cost and long lifetime and it can be regulated frequently. The paper presents a distributing transformer, which employs solid state relay as non contact automatic on-load voltage regulating tap changing switch. And the solid state relay is based on bidirectional thyristor.

## 2. Main Circuit and Operation Process of Non Contact ON-LOAD TAP CHANGER

### *2.1 Main Circuit of Non Nontact On-Load Tap Changer*

The device comprised of transformer, non contact tap changer, circular current limiting circuit and control unit.Its wiring diagram is showed in Fig 1. $w_{10}$ is the primary operating winding of transformer. It works during energization of power Grid. $w_{11}$ and $w_{12}$ are primary regulating winding. $w_2$ is secondary winding of distributing transformer.SSRi(i=1,2,3,4) is zero crossing type solid state relay. Under the action of controlling voltage, it can be on when AC voltage crosses zero and be off when AC current crosses zero. $R_X$ is circular current limiting resistance. It is only connected to the circuit in the process of changing working tap joint. The function of single chip monitoring system is to monitor the output voltage of distributing transformer and to send controlling signal according to the prearranged program. CB is measuring transformer. It offers power and measuring signal for monitoring system.

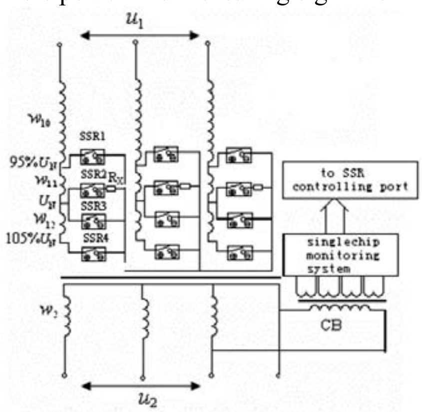


Figure 1. Main circuit of non contact automatic on-load voltage regulating distributing transformer

### *2.2 Automatic Voltage Regulating Process of Automatic Non Contact On-Load Tap Changer*

The storage battery supply power for monitoring system before the distributing transformer is powered on to make SSR3 in on state. When the transformer is switched on, the output voltage of transformer is detected by singlechip monitoring system automatically. If the voltage exceeds permitted range of fluctuation, the automatic on-load voltage regulating program will be operated. The flow chart of automatic on-load voltage regulation is shown in Fig. 2.

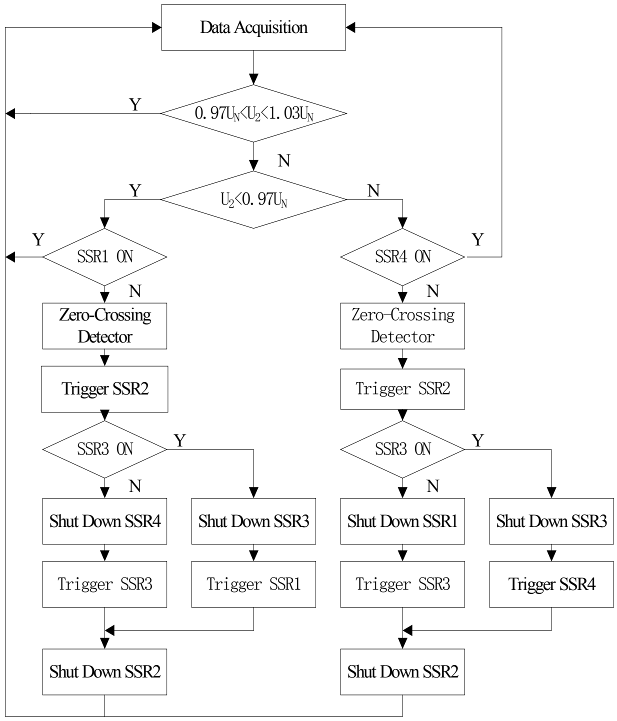


Figure2 Flow chart of automatic on-load voltage regulation

It can be seen from Fig.2 that it connects the current limiting resistance Rx to the tap joint switching circuit firstly, and then switches the tap joint. It can limit the value of circular current.

## 3. Theoretical Analysis of Regulating Winding's Condition When Tap Joint is changed

It can be seen from the operating sequence of each solid state relay in the process of changing tap joint that the regulating winding and solid state relay will make up of closed loop in this process. And the circular current will occur in the loop. The solid state relay will be damaged if the value of circular current excess permitted value. The value of circular current is related to the impedance of the loop and the power factor $\cos\varphi_1$ of transformer's primary side. $\cos\varphi_1$ is smaller as the value of circular current is bigger. $\cos\varphi_{1\min} = 0.2$, namely $\varphi_{\max} = 78.5°$

The sample is $S_9$—50kVA/10kV energy saving distributing transformer. There are 3 tap joints $95\%U_N$, $U_N$ and $105\%U_N$ at primary side. They are near neural point. When the line voltage of transformer's primary side is rated voltage 10kV, current is rated current 2.75A, SSR3 is on, other SSR is off and $w_{10}$ and $w_{11}$ are connected in series as working winding, then line voltage of transformer's secondary side is rated voltage 400V and it work under rated condition. The transformer's short circuit voltage percentage $U_k\% = 4$, short circuit loss $\Delta P_k$ =1150 W, no load current $I_0\%$ =2.5 , no load loss $\Delta P_0$ = 190 W. It can be calculated that the equivalent resistance which is converted to the transformer's primary side $R_T = 23\,\Omega$ ,equivalent impedance $X_T = 32.7\,\Omega$ .

It is assumed that the transformer works at tap joint $U_N$ and current limiting resistance $R_X$=0. Then we analyze the mechanism of the circular current which is occurred in the process of switching tap joint.

If the output voltage of transformer is lower than permitted value, the working tap joint will changed from $U_N$ to95%$U_N$ . During the period from turning on the SSR1 to shutting off the SSR2, the closed loop is composed by regulating winding $w_{11}$, SSR1 and SSR2.And circular current $i$ is occurred. $i$ can be calculated by the equivalent circuit which is shown in Fig. 3. The circuit is also adequate for the condition that tap joint is switched from 105%$U_N$ to $U_N$ . $X_{w11}$ and $R_{w11}$ is equivalent impedance and resistance of regulating winding $w_{11}$ at transformer's primary side respectively. K is equivalent switch of SSR1. And $u_{w11}$ is equivalent power source voltage of the circuit. It is assumed that the winding is uniform. Then according to the relation that winding's resistance is proportional to its turns and impedance is proportional to the square value of its turns, and $w_{10}$ and $w_{11}$ is in series connection, it can be calculated that $X_{W11}$ =0.82 and $R_{W11}$= 1.15 Ω [3].$u_{w11}$ is approximate to 5% of primary side phase voltage (=8164sinωt) , namely $u_{W11}\approx$408sinωt . voltage equation of the loop in Fig. 3 is[4]:

$$iR_{W11} + L\frac{di}{dt} = 408\sin\omega t \tag{1}$$

The solution of (1) is:

$$i = i^{'} + i^{''} \tag{2}$$

Where $i'$ is stable component of loop current. If $R_X$= 0 then

$$\begin{aligned} i^{'} &= \frac{U_{\mathrm{m}}}{\sqrt{R_{\mathrm{W11}}^2 + X_{\mathrm{W11}}^2}}\sin(\omega t - tg^{-1}\frac{X_{W11}}{R_{W11}}) \\ &= 289\sin(\omega t - 35.49°) \end{aligned} \tag{3}$$

$i''$ is transient component of loop current:

$$\begin{aligned} i^{''} &= Ae^{-\frac{t}{\tau}} \\ &= Ae^{-440.37} \end{aligned} \tag{4}$$

So

$$\begin{aligned} i &= i^{''} + i^{''} \\ &= 289\sin(\omega t - 35.49°) + Ae^{-440.37t} \end{aligned} \tag{5}$$

Where A is relatively to the power factor angle . and current value of primary side which are the value that tap joint is not changed. If $\varphi = \varphi_{\max} = 78.5°$ , $i_1(0^-) = -3.81$ when $t = 0^-$ . The direction of $i$ is contrary to that of $i_1(0^-)$ in Fig. 3.

$$3.81 = -289\sin 35.49° + A$$
$$A = 171.59$$

So

$$\begin{aligned} i &= i^{'} + i^{''} \\ &= 289\sin(\omega t - 35.49°) + 171.59e - e^{-440.37t} \end{aligned} \tag{6}$$

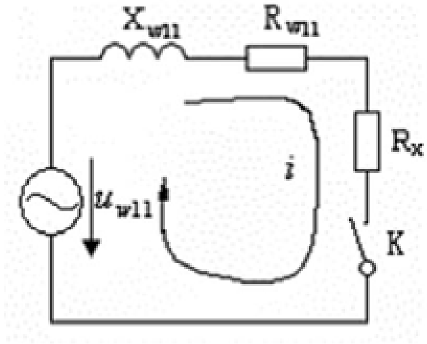


Figure 3. Equivalent circuit in the process of switching tap joint

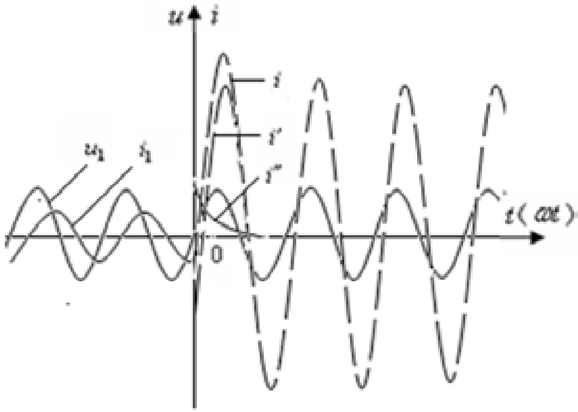


Figure 4. Circular current waveform in the process of regulating voltage to lower value

For observing the variation of current that is through SSR2 when SSR1 is on and off conveniently, it draws the current $i_1$, which is through SSR2 by broken line. The direction of the current is the same as that in Fig. 3. The circular current wave according to (6) is shown in Fig. 4.

It can be seen from the figure that after SSR1 is on at the time of $t = 0$ , value of the current which is through SSR2 (its direction is the same as that in Fig. 3) is increasing from 3.81A, and it be smaller gradually after it reaches $i_m$. And SSR2 is off at the time of $i$ =0 . The overcurrent will occur before SSR2 is shut off in the process of voltage is regulated to a higher value.

If the value of output voltage is higher than permitted value, the working tap joint should be regulated to 105%$U_N$ . The equivalent circuit in Fig. 3 can be used to calculated circular current $i$ too. K is equivalent switch of SSR4. The circuit parameters adopt parameters of w12. If $R_X$ =0 , the value of circuit parameters are not changed because $w_{11}$=$w_{12}$. Thus the equation of circular current is the same to (5). And $i_1(0^-) = -3.81\text{A}$ $i_1(0.)$ =.3.81A . Under this condition, the current direction of SSR2 is not changed whether SSR4 is on or off. Therefore at the time of $t$ =0

$$-3.81 = -289\sin 35.49° + A$$

$$A = 164.97$$

$$i = i' + i''$$

$$= 289\sin(\omega t - 35.49°) + 164.97e^{-440.37t}$$

The waveform is shown in Fig. 5.

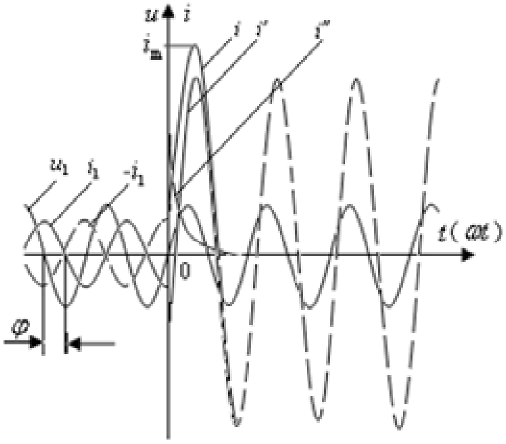


Figure 5. Circular current waveform in the process of regulating voltage to higher value

It can be seen from Fig. 5 that circular current i (the current through SSR2) changed from –3.81A to zero crossing point quickly after SSR4 is on at the time of $t = 0$ . It is different from the process of regulating tap joint for higher the voltage value. SSR2 is off at the time of $i = 0$ . The circular current $i$ doesn't reach its maximum value before SSR2 is off. There are not big circular current occur in the Changing process.

It can be concluded that the occurring mechanism of circular current in the process of regulating output voltage to higher value is different from that in the process of regulating output voltage to lower value. In the former, circular current is occurred by overcurrent in the process of switching tap joint. And the overcurrent value is in relation to impedance of the circuit. In the latter the overcurrent won't occur in the process of switching tap joint whatever the value of circuit impedance is. And the conclusion is verified in laboratory.

AC voltage regulator applies voltage to sample transformer with several voltage levels. And each voltage level is 1kV. It begins with 0V. The output voltage range of the voltage regulator is 0~11kV. During the period of changing tap joint to regulate the transformer's output voltage to higher value, when the applied voltage of primary side is 3kV, overcurrent will occur and fuse will blow. And during the period of switching tap joint to regulate the transformer's output voltage to lower value, overcurrent is not occur even primary side voltage reaches 11kV.

Because overcurrent will occur and its value is in relation to circuit resistance, current limiting resistance must be connected to the circuit during the process of switching tap joint. That is $R_X$ can't be zero.

The connection of $R_X$ reduces amplitude of circular current's stable component and time constant of the circuit. It quicken the attenuation of transient component $i''$ of circular current $i$ and diminish the influence of $i''$ on overcurrent amplitude $i_m$ .

If $R_X$=6.8 Ω then $\tau = 0.227\text{ms}$ . It indicates that the transient component is attenuate to zero after 1.6ms. The magnitude of is determined by stable component.

Then

$$\begin{aligned} i &= \frac{408}{\sqrt{7.95^2 + 0.82^2}} \sin(\omega t - tg^{-1}\frac{0.82}{7.95}) \\ &= 51.05\sin(\omega t - 5.89°) \end{aligned}$$

$$i_{\mathrm{m}} = 51.05\mathrm{A}$$

The sample transformer adopts 40A solid state relay.Its permitted maximum current is 200A in half cycle.And its safety factor is approximate to 4. It is proved that the choice can meet the demand of safety by experiment and sample operation.

## 4. Conclusion

It is proved that the automatic on-load voltage regulation is an effective method to stabilize load voltage by theoretical analysis and experiment.

The variation rule of circular current is different between the process of regulating voltage to higher and lower value. In the former process, the circular current crosses zero after its amplitude reaches the peak value so the current limiting resistance must be series connected to the circuit. While in the latter process, the circular current crosses zero before its amplitude reaches the peak value.Therefore it needn't connect with current limiting resistance. The value of current limiting resistance can be determined according to the criterion that suppresses the amplitude of circular current stable component near rated value of SSR.

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